International Beacon Satellite Symposium BSS-2016
Trieste, Italy

Ionospheric TEC estimations with the signals of geostationary GNSS and SBAS satellites

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Abstract. With the development of receiving equipment and GNSS and SBAS constellations, the coherent dual frerquency L band transmissions are now available from a number of geostationary satellites. These signals can be used for ionospheric total electron content (TEC) estimations. In this work, we present the results of the comparison of the noise patterns in TEC estimations using signals of geostationary satellites of augumentation systems – Indian GAGAN, European EGNOS and American WAAS, as well as the signals of Chinese COMPASS/Beidou navigational system. We show that noise level in TEC estimations based on geostationary satellites of COMPASS/Beidou system is times smaller than for SBAS and corresponds to those of GPS/GLONASS at the same elevation angles. We also discuss the capabilities of geostationary TEC observations in connection with recent G4 geomagnetic storm of March 2015.

Key words: Ionosphere, Total Electron Content, GNSS, SBAS

During last two dacades data from Global Navigational Satellite Systems (GNSS), such as GPS and GLONASS, are actively used in ionospheric studies[1,3,4,6,7]. TEC estimations based on dual frequency phase and/or group measurements are the input data for Global Ionospharic Maps (GIM)[5,12] as well as for 4D spatio-temporal ionospheric tomography procedures[7]. Recently along with widely used GPS/GLONASS satellites there is a possibility to apply geostationary satellites of COMPASS/Beidou navigational system and geostationary satellites of Satellite Based Augumentation Systems (SBAS), such as IGAGAN, WAAS and EGNOS, for ionospheric TEC estimations[8,9].

The main advantage of geostationary TEC observations compared to GPS/GLONASS is almost motionless ionospheric pierce point (IPP). It provides the possibility to analyze long-term continous data series for the selected "satellite-receiver" pair instead of rather short 2-6h records as for GPS/GLONASS. Nevertheless, low elevation angles of geostationary satellites already at midlatitudes require the spatial gradients of electron density to be taken into account while analyzing obtained data.

Currently there are eleven (three WAAS - prn133, prn135, prn138; two GAGAN - prn127, prn128; one EGNOS - prn136; five COMPASS - C01, C02, C03, C04, C05) geostationary satellites transmitting signals at pairs of coherent L-band frequencies, which can be used to estimate ionospheric TEC. The number of receiving sites capable to work with the majority of GNSS and SBAS satellites is also rapidly increasing. In common access in particular are the observations of the IGS MGEX[10] network. To analyze noise level of TEC estimations with geostationary GNSS and SBAS signals we used data from two receiving sites – test receiver MSU located in Moscow, Russia and STFU (one of IGS MGEX sites) located in Palo Alto, California. The undisturbed (Kp~2..3, Dst~-4..-44) day May 12, 2015 was chosen for the analysis and 100 sec. TEC RMS was used as the noise level estimate. Table 1 shows the summary of the obtained results. It is clearly seen that for GAGAN satellites mean TEC noise is ~0.6TECU with maximum values reaching 1.5TECU, when at the same time for COMPASS/Beidou satellites at close elevation angles TEC noise is significantly smaller, with mean and maximum values ~0.06TECU and ~0.2TECU correspondingly, which is comparable to TEC noise for GPS/GLONASS observations at the same elevations. TEC noise for EGNOS SES-5 satellite reaches up to 16TECU, which is not suitable for ionospheric studies. TEC noise for WAAS satellites with mean and maximum values ~0.07TECU and ~1.4TECU correspondingly is comparable with those of GAGAN observations. Nevertheless, additional smoothing is required to apply GAGAN and WAAS data for ionospheric studies. Thus, TEC estimations based on geostationary COMPASS/Beidou satellites provide the best noise level among all geostationary GNSS and SBAS systems.

Table 1. Typical TEC noise for various GNSS and SBAS systems for studied test day.

Satellite, Elevation angle	Receiving station	TEC RMS$_{100}$, TECU	
		Mean	Max
EGNOS SES-5 (prn136), α=20°	MSU	4.96	16.08
GAGAN GSAT-8 (prn127), α=25°	MSU	0.56	1.48
GAGAN GSAT-10 (prn128), α=15°	MSU	0.61	1.18
Compass-G5 (BDS5), α=25°	MSU	0.053	0.188
Compass-G6 (BDS2), α=16°	MSU	0.066	0.257
WAAS Intelsat Galaxy 15 (prn135), α=45°	STFU	0.68	1.29
WAAS TeleSat Anik F1R (prn138), α=44°	STFU	0.7	1.6
WAAS Inmarsat 4-F3 (prn133), α=43°	STFU	0.68	1.42
GPS/GLONASS, α =5-15°	MSU	0.05	0.1

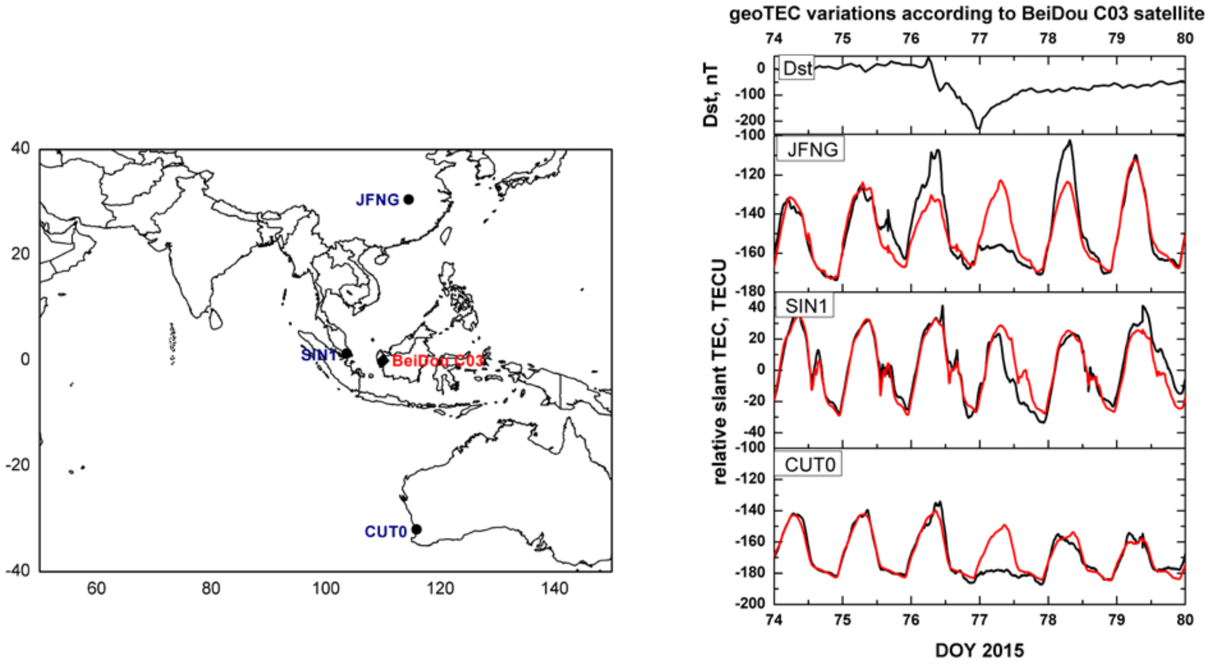

Figure 1. TEC variations (right) during St. Patricks Day 2015 geomagnetic storm according to COMPASS/Beidou C03 geostationary satellite and the geometry of observations (left).

Our results also show that for GAGAN reception at two receiving sites in Moscow and Irkutsk separated by ~5000km, the noise in TEC estimations is correlated for both observation sites for the selected satellite suggesting that it is strongly satellite-dependent [8]. Such an effect was not obsereved for other SBAS and GNSS geostationary satellites.

Next, we demonstrate the capabilities of geostationary TEC estimations with COMPASS/Beidou satellites for the analysis of ionospheric effects of geomagnetic storms taking as an example recent severe (G4) geomagnetic storm on March 17-20, 2015 [9]. Data from three receivers CUT0, JFNG and SIN1 of IGS MGEX network in Australian and South-East Asian sector were used for the analysis. Fig. 1 (left) presents the geometry of Compass (C03) satellite observations and corresponding TEC variations compared with Dst index during St.Patricks storm 2015 (right). Black curves represent TEC variations, red ones their 4-day mean undisturbed values. For the midlatitude station of northen hemisohere JFNG intensive positive ionospheric storm (with excess of undisturbed TEC values of ~25TECU) during day 76 (March 17, 2015) is followed by the depression of diurnal TEC variability during day 77 (March 18, 2015). During day 78 (March 19, 2015) positive ionospheric storm is observed at JFNG station. For nearequatorial station SIN1 and midlatitude station of southern hemisphere CUT0 positive ionospheric storm during day 76 (March 17, 2015) is not so distinct, at the same time the depression of diurnal TEC variability during day 77 (March 18, 2015) is also obsereved. Note that the effect of the depression of diurnal TEC variability is decreasing closer to geomagnetic equator. Thus we observe the asymmetry in ionospheric responce to this geomagnetic storm in north and south, hemispheres, caused by complicated combination of the processes responsible for positive (meridianal winds) an negative (neutral composition change) ionospheric perturbations [11,13].

Conclusions. Our results show the capability of using dual-frequency coherent signals from geostationary SBAS and GNSS satellites for continuous monitoring of ionospheric TEC in quite and disturbed geomagnetic conditions. The main advantage of these observations is almost motionless IPP. At the same time, it is necessary to take into account greater level of noise compared to GPS/GLONASS in geostationary TEC observations. The research conducted in present paper showed that it is preferably to use geostationary COMPASS/Beidou satellites.

Intensively growing number of receivers in multisystems networks and increasing number of dual (and more) frequency geostationary satellites in SBAS and GNSS constellations provide the opportunity in future to incorporate these types of measurements to ionospheric tomography [7] and interferometry routines [2], if the noise level in geostationary TEC estimations will be reduced.

Acknowledgements. Authors acknowledge financial support of Russian Scientific Foundation (project 14-17-00637).

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